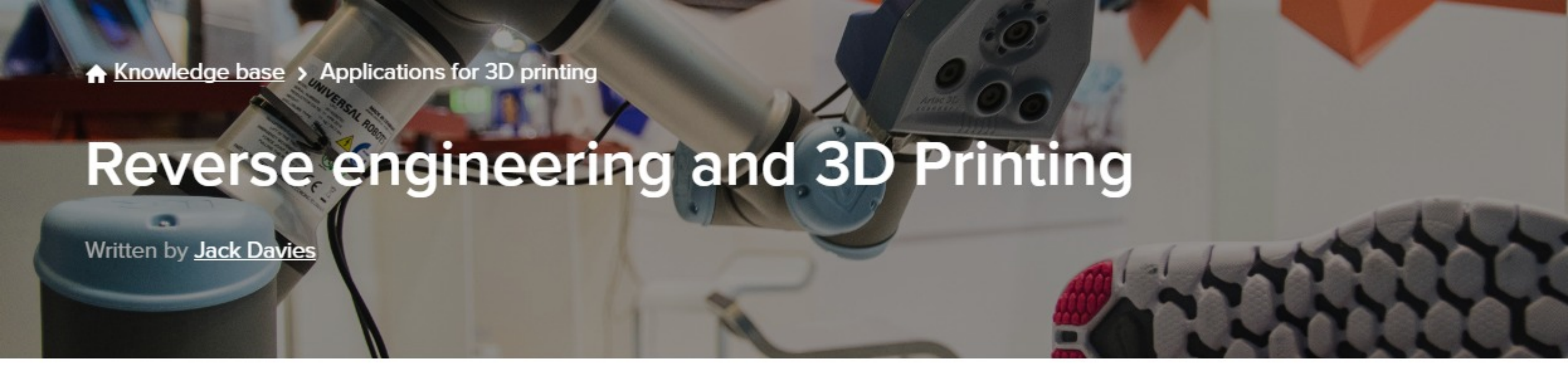


Reverse engineering and 3D Printing

Written by Jack Davies

This article discusses how reverse engineering and 3D printing can be used collaboratively. Methods of reverse engineering, common applications and several case studies relating to 3D printing are also presented.

Table of contents

Introduction

Reverse engineering is one method that is used to generate digital 3D files of existing parts. This article will explore common methods of reverse engineering and how this process can be incorporated into the design process to produce prototype and replacement parts quickly and efficiently using 3D printing. The article will also present 3 case studies where reverse engineering and 3D printing have been used collaboratively to produce an optimal design solution.

What is reverse engineering?

Reverse engineering is the process of studying existing parts or products to gain insight into how they are designed and/or made. It usually involves complete disassembly and documentation of all parts or assemblies, followed by computer digitisation, recreating them as 3D files.

Reverse engineering can be used to capture the surface data of very complex shapes

Reverse engineering applications

The most common applications for reverse engineering include:

The generation of 3D files that represent complex and organic surfaces	• Medical & dental implants • Automotive • Aerospace • Ergonomic design
Verifying parts to check dimensional compliance	• Precision engineering • Lean manufacturing and QA processes • Batch manufacturing part comparison
The measurement of parts that are no longer in production	• Castings • Parts without digital documentation • Legacy parts
Defect detection	• Review of internal part compliance • Detection of cracks, voids or imperfections

Reverse engineering methods

The reverse engineering method implemented for part measurement can vary based on the complexity of the part, and the intended use of the information. Reverse engineering can be separated into two main categories; 3D scanning & physical measuring.

3D Scanning

3D scanning techniques used for reverse engineering have several fundamental commonalities:

- The measurement device does not come in contact with the part
- Digital files are “constructed” from measured data (either a series of points or mesh elements)
- The geometry of physical objects is collected with hundreds of thousands or millions of measurements.

Laser Scanning - Laser scanning scans the surface of an object and captures data represented as a collection of points (a point cloud), which is then be used to generate a 3D surface. This enables parts that would be very difficult to precisely measure and 3D model, to be digitised and accurately reproduced. Laser scanning is best suited for free-form surfaces of medium detail and non-uniformity, e.g body panels, metal castings. Data collected via laser scanning can also be integrated with existing solid 3D models, known as hybrid modelling.

Laser scanners can either be handheld (requiring the user to move around the object capturing data points) or fixed (requiring the part that is being scanned to be manipulated). The mounting of laser scanners on robotic arms for accurate surface tracking and high repeatability is also becoming more common.

3D scanners are regularly used in the automotive industry

Laser scanning is widely used in the automotive industry where hand sculpted clay models are created then scanned to generate a 3D model for further testing and refinement.

CT Scanning - Industrial computed tomography (CT) scanning uses X rays to create an accurate representation of a component. CT scanners work by placing an object on a turntable between an x-ray tube and a detector. The detector captures multiple x-ray images of an object as it rotates 360 degrees, acquiring the outer dimensions, internal geometry and density within the object’s walls. The series of 2D images are then run through a reconstruction algorithm that creates a 3D volumetric model.

CT scanners are generally large, expensive industrial machines that the object to be measured is placed inside of.

One major benefit of this type of reverse engineering is that this technology is able to inspect a part both internally and externally, in a non-destructive way, creating highly detailed 3D models with complex geometry.

The ability to see inside a component is beneficial as it allows internal components to be seen in their functioning position. It is also especially useful to inspect and verify parts used in critical applications such as aerospace. These parts can be CT scanned to reveal any imperfections or voids which could lead to failure once the part is in use.

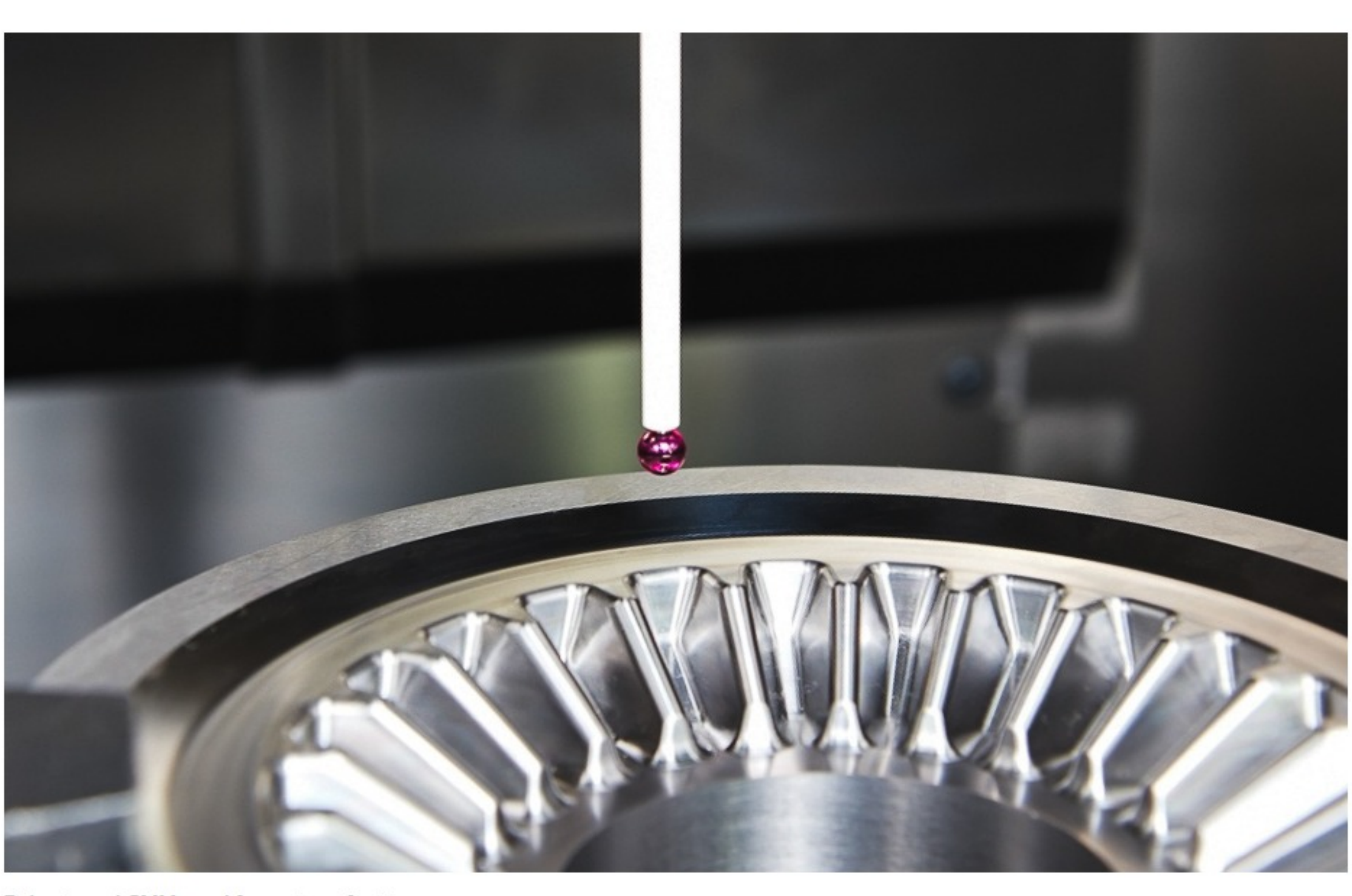
CT scanning is also used for dimensional accuracy verification in manufacturing. A manufactured part is scanned and the corresponding 3D model produced from the scan data is then “laid-up” over the original 3D model of the design. Automated software then detects any variations in dimensions and determines whether they are within an acceptable range.

Physical measurement

Physical measurement techniques vary from 3D scanning methods in that they:

- Require direct contact with the object being measured
- Typically more accurate than 3D scanning techniques
- Rely heavily on the operator to achieve accurate measurements

CMM Measuring - A coordinate measuring machine (CMM) uses a probe to manually scan certain features of a physical part. It is usually used to verify dimensions of parts rather than to digitise them completely but it is also possible to generate a point cloud using a CMM which can then be converted into a 3D file. This method is best suited for simple parts where high accuracy is important.

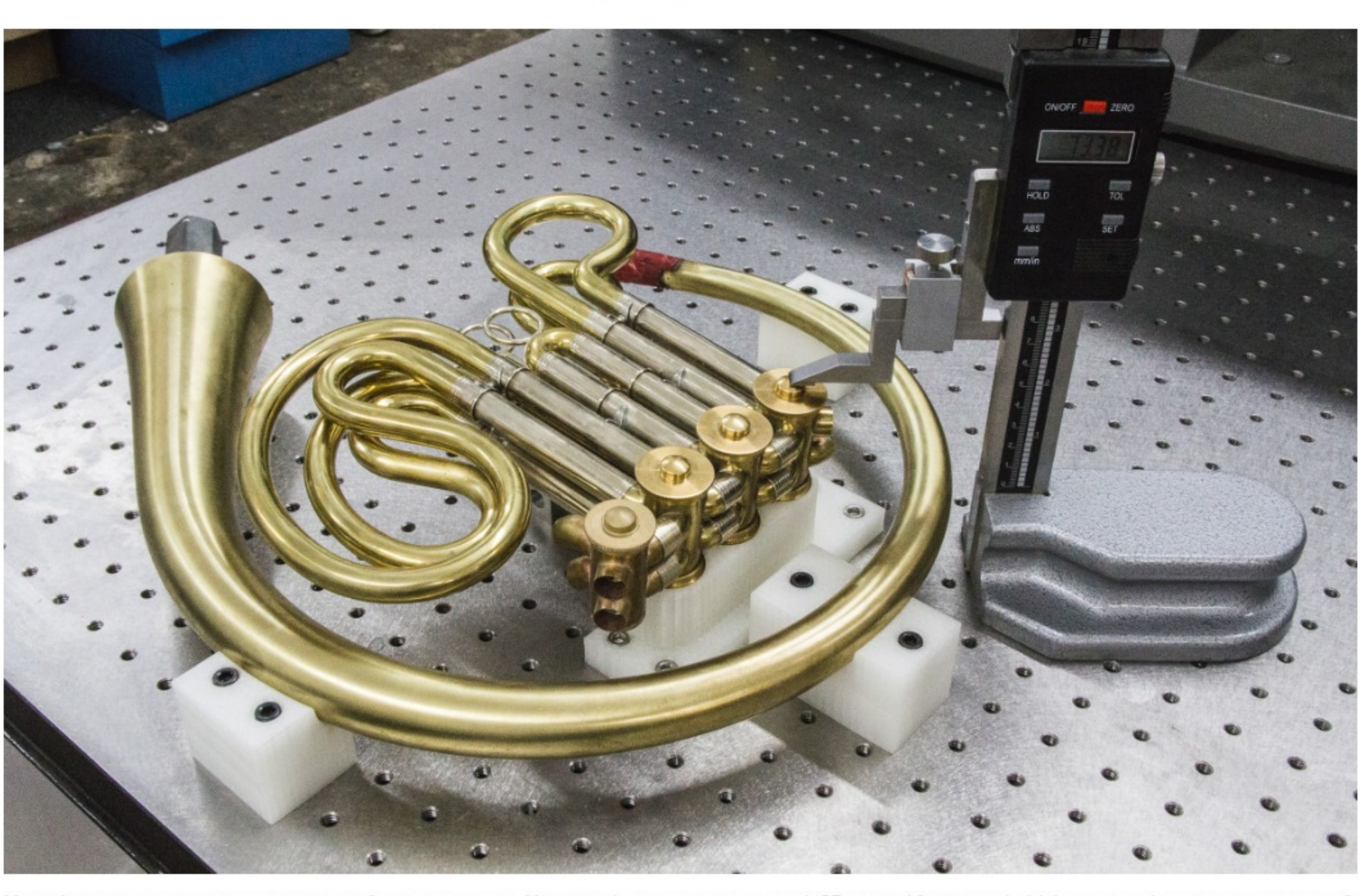


Ruby tipped CMM used for part verification

CMM’s are often used in batch manufacturing where a sample of parts are selected from a batch and measured to verify compliance.

Manual Measuring - Manual measuring is a much simpler and accessible method of reverse engineering in which a 3D model is created by manually measuring features of a part and using traditional CAD software to produce the 3D file. It is generally slower than 3D scanning as each feature has to be carefully measured, modelled and then verified.

The main advantage of manual measurement is the 3D file is usually a more accurate representation of the physical part than 3D scanning as long as proper measuring tools and methodologies are implemented. The complexity of parts and features that can be accurate be measured is more limited than with 3D scanning techniques.

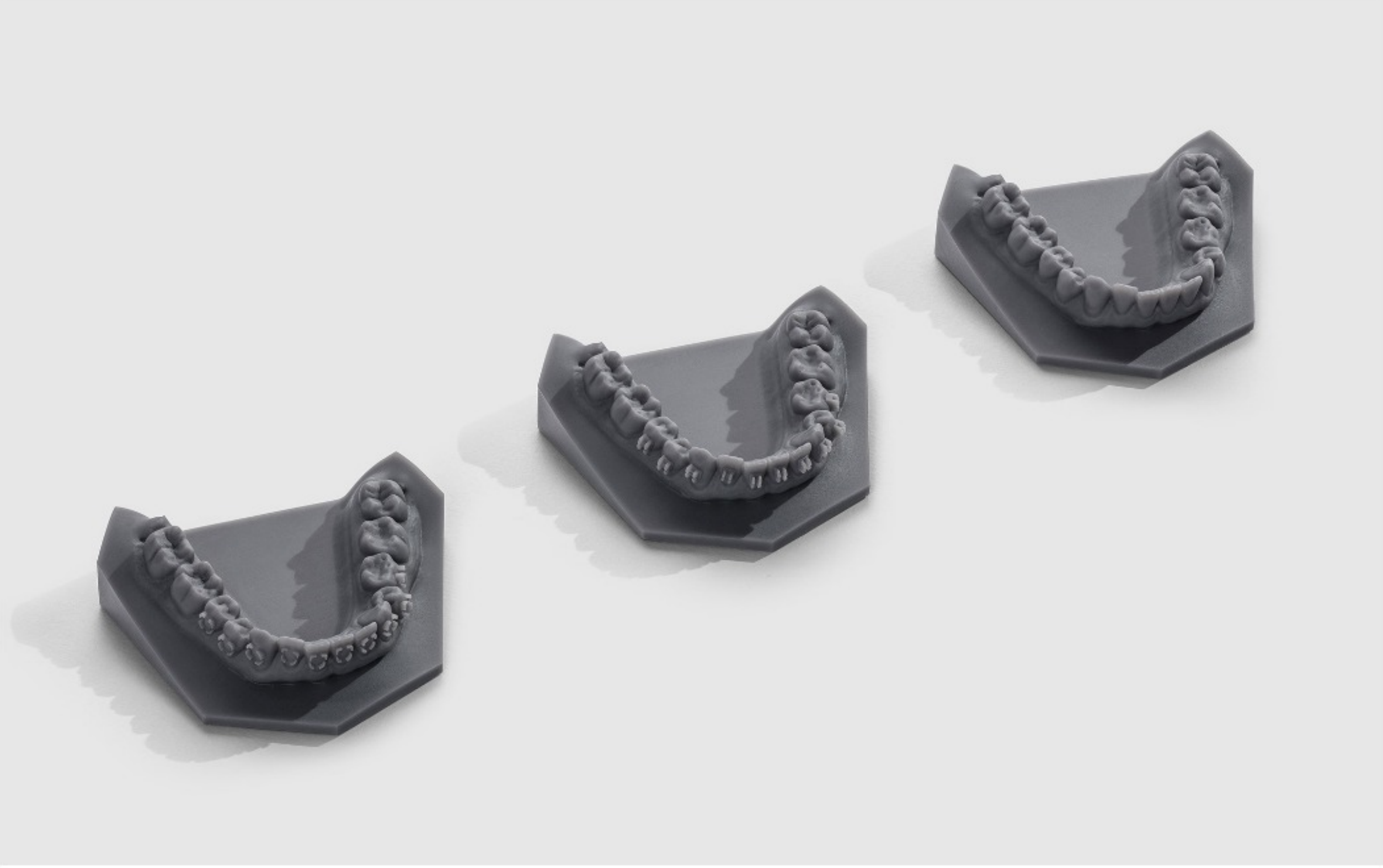


Manual measurement is an accurate way of measuring parts. Here it is done in conjunction with 3D printed fixtures to hold the part in place (image courtesy of Markforged)

Reverse engineering and 3D printing

Reverse engineering and 3D printing are often used in tandem in industry. For objects with complex or organic geometry reverse engineering techniques can be implemented to accurately produce a 3D model of the surfaces.

A common application of 3D scanned files is to produce a reverse of a scanned surface in CAD. The reverse surface can then be 3D printed ensuring perfect mating between the printed part and the original scanned surface. This technique is adopted regularly by the medical and dental industry for the production of everything from hearing aids to dental implants.



A 3D scan of a patient's teeth printed with an SLA printer (image courtesy of Formlabs)

Reverse engineering and 3D printing are also used collectively in manufacturing for the production of 3D printed injection molds (an object is scanned and a mold is then 3D printed) and tooling (where a tool or part surface is scanned and a manipulator or grip is then 3D printed that mates with the object perfectly). Reverse engineering using CT scanning also allows the measurement of complex internal features (this of particular relevance for parts the have fluids move through them). The additive nature of 3D printing means that replicating these types of components is much easier when compared to traditional manufacturing techniques.

Case Study 1 - Zortrax / Triumph Daytona Motorcycle

This project integrated reverse engineering for quick scanning and modeling of a complex system (motorcycle frame) along with 3D printed to rapidly and accurately print a prototype parts.The goal was to take an existing motorcycle completely customise the body panels. The project demonstrated how 3D printers can benefit the automotive industry as a method for rapid prototyping allowing quick feedback on form and fit.

The begin the process the bike was disassembled so that the frame could be measured. A 3D scanner was used to produce a model of the bike so that all the new components could be designed to fit perfectly with the existing frame using existing mount points.

Over 180 plastic parts including the fairings, tank casing, seat, windshield, lights, and mirrors were redesigned on the original 600cc motorbike and replaced with FDM printed parts using a range of filaments each with properties specific to their location on the bike. After the new components were printed, they were post-processed with a series of treatments that included smoothing down, undercoating, grinding, and painting. The new components could then easily be assembled onto the bike.

A hand held 3D scanner is used to produce a 3D model of the bike frame (image courtesy of Zortrax)

In little over 1 month the designers and engineers working on the project we able to produce parts that completely revised the overall look of the bike. This type of rapid feedback, the control they had over the design process and the ability to produce complex parts in a single print produced a result that would not have been possible with any other technology. The short amount of time this design was implemented in and the low cost further demonstrate that designers can use desktop 3D printing technology to create and test functional prototypes at any stage of production.

Case Study 2 - Surgical dental guides

Within the dental industry reverse engineering and 3D printing have become common practice producing surgical guides for dental implants and surgical planning models. Initially an impression of the patient's is created using a plaster mold. The plaster mold is then 3D scanned to generate a 3D file. Research has shown that this method of reverse engineering generates more accurate models when compared to direct scan of the patient's mouth. Dentistry specific modelling software is then used for the design and optimisation of the surgical guide so that it matches the patient's teeth perfectly. The design is then printed using biocompatible material, sterilised and is ready to be used in the surgical procedure. The use of a 3D printed guide reduces procedure time and allows for more precise control during the dental surgery ultimately resulting in improved patient outcomes.

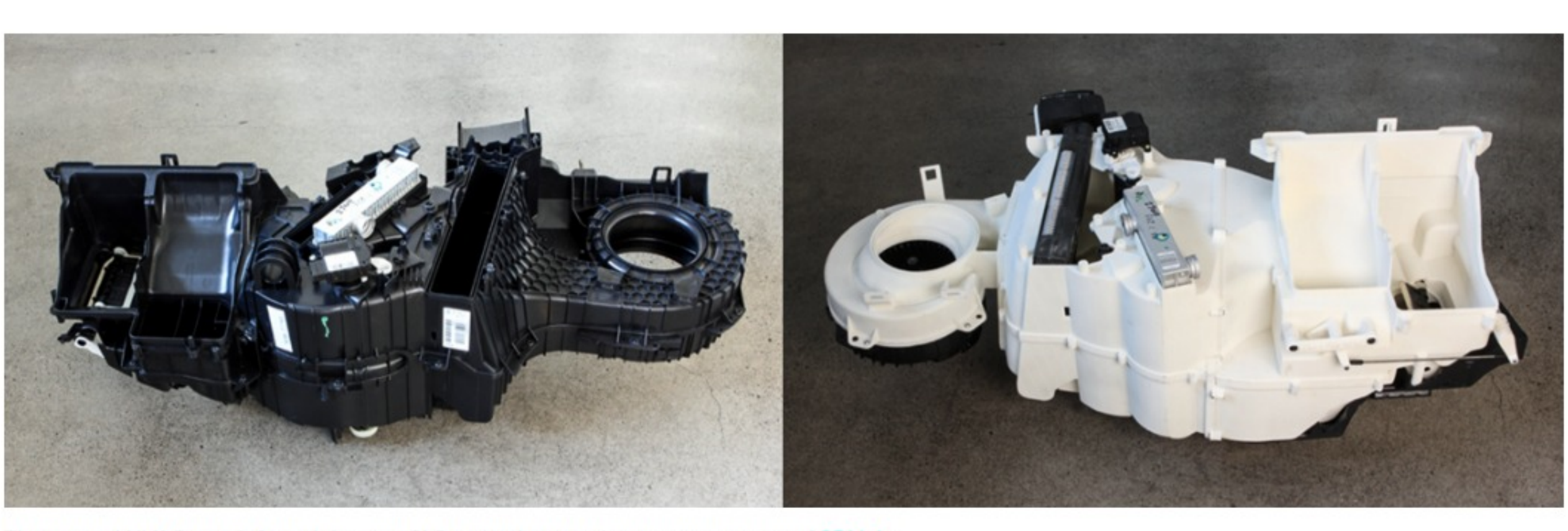
An accurate tool placement guide. Reverse engineering scan data was used to ensure a perfect match to the patients teeth (image courtesy of Formlabs)

Case Study 3 - HVAC unit for right-hand drivers

This case study focuses on the conversion of a left-hand heating, ventilation, and air conditioning (HVAC) unit into a right-hand unit to fit the modified interiors of Chevrolet and GMC trucks completed by 3D Hub (a product development company based in New Zealand). It was decided the new HVAC unit would be developed by acquiring 3D measurements of the current left-hand components. This information was then integrated into CAD software so that the design could be converted and then manufactured via the company’s 3D printing processes.

The project began with the disassembly of the truck. After removal of the dashboard and transposition of the steering wheel and column the HVAC unit was removed to allow access to the vehicle's firewall. Positioning targets (datum targets) were applied onto the firewall surface as project reference points. The removed HVAC unit was then scanned to capture critical design features and this information was used to plot the new design of the replacement units. By using scan data from the firewall, dashboard, glove box and ducting, a 3D environment was produced in CAD. This gave the designers a unique insight into clearances and the available build space that the new HVAC unit was required to fit inside. This information coupled with the scan data from the original unit allowed the project team to optimise the geometry and configuration of the replacement.

Once all parameters were checked and verified against the imported scan data the converted HVAC unit was printed in SLS nylon. SLS nylon was selected due to its mechanical properties and process design freedom. The prototype was mounted and tested in the vehicle. Due to the accurate scanning data, only minor adjustments needed to be made before the final product could be manufactured.



The original HVAC unit (left) and the new SLS printed unit (right) (image courtesy of 3DHub)

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